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PIPELINE ADVANCED LEAK-LOCATION SYSTEM (PALS)

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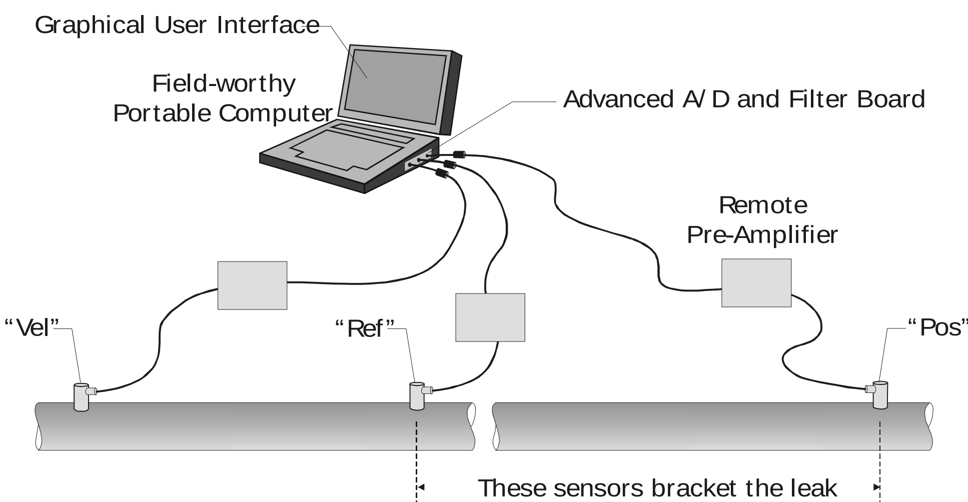
ABSTRACT

The Pipeline Advanced Leak-Location System (PALS) is used to locate leaks in underground, pressurized fuel pipelines. The PALS is a portable system, and is used only after a leak has been detected. An estimate of the performance of the PALS was made, based on field tests of the system on 4- to 10-in.-diameter bulk and hydrant fuel pipelines located at three military facilities and on the 12-in.-diameter Navy Test Loop at the SERDP Test Pipeline at EPA's facility in Edison, New Jersey. The results of these tests showed that, with the PALS sensors spaced at distances up to 200 ft, the system located leaks to within 3 ft of where they actually were. For the longer distances between sensors, the PALS' accuracy was better than 1.5% of the sensor separation distance. The system was routinely operated on pipe segments of 500 ft or longer, which made it possible to mount the sensors on the pipe at available access points, without the need for excavation.

SYSTEM DESCRIPTION

The PALS, shown below, is a portable, passive acoustic system. It is comprised of three acoustic sensors, three small pre-amplifiers, and a notebook computer having a data acquisition card. The sensors are attached with epoxy directly to the pipe wall or to a flange connection. Each sensor measures the acoustic signal generated by the turbulent flow through a hole in the pipe. A pair of sensors brackets the leak and determines the location of the leak relative to one of the two sensors, called the "reference" sensor. A second pair of sensors, which do not bracket the leak, is used to measure the speed of propagation of the



Schematic diagram of the PALS. *Leaks are located between the Reference (Ref) and the Position (Pos) sensors, and the propagation speed is measured between the Ref and the Velocity (Vel) sensors.*

acoustic wave in the pipe. For the leak to be properly located, the distances between the sensors must be known—since the measurement made by the PALS determines the location relative to the reference sensor. A leak-location measurement can take as little as 2 to 5 minutes to complete.

The acoustic signal produced by a leak can be masked by background noise. The time series that is recorded at each acoustic sensor—and that contains the leak signal—is "banded," and appears random in nature. *Signal processing* techniques, which permit the detection of the signal in the presence of background noise, must therefore be applied. Simple systems that attempt to infer the location of the leak from the relative amplitude of the acoustic signal measured at two sensor locations do not work reliably. The most widely used approach to acoustic leak location is correlation analysis. In this approach, a correlation function is computed from the time series collected at the two sensors bracketing the leak. This approach is also not robust, because the frequency band containing the leak signal is not known prior to the measurement and will vary as a function of pipe diameter, wall thickness, wall material, fluid, pipe geometry, and propagation mode. If the signal band is not known, the location estimate may be highly contaminated by noise.

In 1991, Vista Research, Inc., demonstrated an improved methodology for locating leaks in pressurized underground fuel pipelines using a passive-acoustic leak-location system.[1] Using a coherence-based signal-processing algorithm, Vista Research realized a 100-fold improvement in performance (in terms of the size of the leak and the spacing between sensors) vis-à-vis the traditional correlation analysis approach. Field tests on a 2-in.-diameter pipeline containing fuel, and pressurized to 30 psi, showed that, with a sensor spacing of 125 ft, leaks could be determined to within several feet of their actual locations. These tests demonstrated that passive acoustics could be used to find leaks of environmental interest in underground fuel pipelines.

The PALS is a real-time system that uses the coherence function to determine the existence of an acoustic signal and to determine the frequency band that contains the signal. The system is easy to set up and use, and can be operated by a field technician with a minimal amount of training.

Field Test Results

A series of field tests on different types and configurations of underground pipelines were conducted between April and October 2000 to demonstrate and validate the capability of the PALS for locating leaks on pipeline systems at operational facilities without impacting the conduct of operations. A brief summary of the test sites and the test results is presented below.

A 10-in.-diameter, bulk fuel pipeline at the U. S. Navy's Construction Battalion Center (CBC), Port Hueneme, California. This underground pipeline, which is 457 ft in length, extends from a pump station, under a road and an asphalt-paved area, to a marine fueling pier.

1. E. G. Eckert, J. W. Maresca, Jr., R. W. Hillger, and J. J. Yezzi. "Location of Leaks in Pressurized Petroleum Pipelines by Means of Passive-Acoustic Sensing Methods." In: *Leak Detection Monitoring For Underground Storage Tanks, ASTM STP 1161*, Philip B. Durgin and Thomas M .Young, Eds., Philadelphia: American Society for Testing and Materials (1992).

For these tests, the pipeline was filled with water. Excavations made with a backhoe provided access to the pipeline. At two of the five access areas, removable pipe plugs that have holes of different diameters were used to generate leaks during the tests. Backfill conditions during the testing included both saturated and unsaturated sand and pea gravel, and pressures ranged from 25 to 125 psi. The tests were conducted on the middle sections of the pipeline, with distances of 18.1 ft and 123.7 ft between bracketing sensor pairs. More than 10 days of testing occurred between 25 April and 1 August 2000. The major source of background noise was light vehicular traffic. The PALS located leaks with an error of only 0.1 to 5 ft.

Two 1,000-ft, 6-in.-diameter hydrant fuel pipes on the operational flight line at the Little Rock Air Force Base (LRAFB), Little Rock, Arkansas. The LRAFB is the home of the 314^{th} Airlift Wing and is the only C-130 training base for the Department of Defense (DOD). In addition to C-130s, jets (e.g., F-14s and F-18s) and other aircraft also use the airfield. Two of the 30 hydrant fuel lines were tested. There are six hydrant pits along each line at intervals of 140 ft. Sensors could be placed on either line at any of these hydrant fueling pits. The lines were filled with water and pressurized to 100 psi for the leak-location tests. The tests were conducted on 7-9 August 2000 during routine flight operations for 50 C-130 aircraft. These operations occurred continuously throughout the day and night. The results of simulated leak tests showed that the PALS could locate leaks at sensor separation distances up to 700 ft during C-130 flight line operations. The PALS located the simulated leaks to within several feet (i.e., 1% of the sensor separation distance).

The 12-in.-diameter Navy Test Loop of the Strategic Environmental Research and Development Program (SERDP) Test Pipeline Facility (STPF). The STPF pipeline, located at the U. S. Environmental Protection Agency (EPA) site in Edison, New Jersey, is 1,015 ft long. It was filled with water for these tests, conducted 14-16 August 2000. The results of 18 tests are summarized in the table below. Ten different sensor separation distances, ranging from 135 to 517 ft, were used; the median separation distance was 360.0 ft. In addition, there were a variety of leak locations and sensor positions. All tests were conducted at a pressure of 70 psi. For half of the tests, the reference sensor was mounted on a blind flange at the end of a vertical riser, and the other sensors were mounted directly on the pipe wall. The accuracy did not change with leak rate or the relative leak location. In these tests, leaks were located to within 3 ft for sensor separations less than 200 ft and to within 1.5% of sensor separation distances greater than 200 ft.

Summary of the Accuracy of the Leak-Location Test Results Conducted at the STPL Test Facility for Sensor Separation Distances between 159.5 and 516.5 ft

	PALS Location Error (ft)	**PALS Location Error (% of Sensor Separation)**
Average	3.10	1.10
Median	2.65	0.80
Standard Deviation	2.02	0.77

Two different types of hydrant fueling systems at Fort Campbell, Kentucky. Two sets of tests were conducted on 24-26 October 2000, one on a 550-ft segment of 8-in.-diameter bulk pipe that is part of the Ft. Campbell Army Airfield hydrant fueling system, and the other on a 2,300-ft loop of 4-in.-diameter aluminum piping at the Sabre Army Heliport. There was fuel in both lines during the testing, and both were pressurized to 70 psi. Simulated leaks were generated at the ends of the lines. The PALS achieved better performance on the heliport line than on the airfield line. It was observed during the tests on the airfield line that system performance was degraded due to the presence of many elbows at the ends of this line. Tests on the heliport line showed that, with distances of 600 ft between the sensors bracketing the simulated leak, the PALS could locate leaks with an accuracy of better than 1% of that distance.

The results of these tests are particularly significant because the protective coating on the pipe did not have to be removed. In this instance, it was found that the sensors could be mounted on the flanges connecting adjacent sections of piping rather than directly on the pipe wall itself. If the protective coating is removed, it has to be carefully restored at the completion of the tests.

SUMMARY

The PALS was field-tested over a wide range of leak rates, backfill conditions, pipeline configurations, and background noise conditions. Each of the field tests provided different and realistic pipeline configurations reflecting operational conditions that could be encountered in the use of the PALS. It is significant that the system was successfully deployed on the flight line of an Air Force base during routine operations.

The PALS achieved approximately the same degree of accuracy in all the field tests. For sensor separation distances less than 200 ft, its accuracy was within 3 ft. For longer sensor separation distances it was better than 1.5% of the distance. In three of the field tests, the PALS was successfully and routinely operated at sensor separation distances of more than 500 ft. This makes the system operationally practical, because it means that for most bulk and hydrant lines, the sensors can be mounted on the pipe at available access points without the need for excavation. It was also found that the sensors could be mounted on the ends or sides of a flange connection without sacrificing performance. This is important because it means that the pipe coating used for corrosion protection does not have to be removed in order to perform a leak-location test.